

FINAL Report to the National Aeronautics and Space Administration of:  
QUANTITATIVE ANALYSIS OF THE CHROMOSPHERIC  
SPECTRUM OF FE II

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## QUANTITATIVE ANALYSIS OF THE CHROMOSPHERIC SPECTRUM OF Fe II

Philip G. Judge, P.I. (University of Colorado)

This NASA grant covers my ADP research program involving the detailed spectroscopic study of the chromospheric spectra of Fe II.

### 1 Progress in the past 6 months:

Results of the analysis of giant star spectra have appeared in *Astrophysical Journal Supplement Series*. Another paper (Judge, Jordan and Feldman) has been accepted for publication in the *Astrophysical Journal*. Additional work has been initiated on solar spectra in comparison with stellar spectra.

### 2 Abstracts of Papers Published and in press

#### FE II EMISSION LINES. I. CHROMOSPHERIC SPECTRA OF RED GIANTS

*Ap. J. Suppl.*, 77, 75.

High quality, high-dispersion, long-wavelength IUE spectra of three well-studied giant stars,  $\alpha$  Boo (K1 III),  $\alpha$  Tau (K5 III) and  $\beta$  Gru (M5 III), are constructed using a “difference filtering” algorithm developed by Ayres. Measurements of all the emission lines seen between  $\lambda\lambda 2230$  and  $3100 \text{ \AA}$  are tabulated. We take special care to measure all accessible Fe II lines between the  $3d^6 4s$ ,  $3d^7$  and  $3d^6 4p$  configurations including upper limits for absent (but important) members of multiplets.

The emission spectrum of Fe II is discussed in comparison with other lines (e.g. Mg II  $h$  and  $k$ ) whose formation mechanisms are well understood. We relate systematic changes in the Fe II spectrum to the different physical conditions in the three stars, and give examples of line profiles and ratios which can be used to determine conditions in the outer atmospheres of giants. We conclude that most of the Fe II emission results from collisional excitation and/or absorption of photospheric photons at optical wavelengths, but some lines are formed by fluorescence, being photo-excited by other other strong chromospheric lines. Between 10 and 20% of the radiative losses of Fe II arise from 10eV levels radiatively excited by the strong chromospheric H Ly $\alpha$  line. Total radiation losses in Fe II lines from red giant chromospheres are less than the losses from Mg II  $h$  and  $k$ , in sharp contrast to recent models of the solar chromosphere. We ascribe this difference to mainly to radiative transfer effects instead of poorly-known collision rates.

The data presented here will be used in future papers to constrain atomic excitation parameters and models of the chromospheric emitting regions and winds.

#### FE II EMISSION LINE DIAGNOSTICS OF THE SUN AND STARS

in *Stellar Atmospheres: Beyond Classical Models*, eds. I. Hubeny and L. Crivellari, Dordrecht: Kluwer, p. 291

Iron-group elements have a complex term structure owing to the incomplete 3d shell. The resulting line spectra are unique, although complex, spectral diagnostics since the lines span wide ranges of excitation conditions and optical depths. In this paper UV lines of Fe II, the most prominent ion of the iron group in astrophysical spectra, are examined in SKYLAB (SO82B) spectra of the Sun and IUE spectra of cool giant stars. The line excitation and formation are discussed and some implications for the structure of solar and stellar atmospheres are described.

## FE II EMISSION LINES. II. EXCITATION MECHANISMS IN COOL STARS

*Ap. J., in press*

We discuss excitation mechanisms for the "resonance" transitions (between the  $3d^64s, 3d^7$  and  $3d^64p$  configurations) of Fe II observed in emission in the near-ultraviolet spectra of cool stars. Our analysis is based upon: (a) emission measure analysis of previously measured lines in IUE spectra of cool giants, (b) discussion of the behavior of Fe II lines observed above the solar limb from SKYLAB spectra, (c) approximate radiative transfer calculations in a 59 level Fe II model atom using mean escape probabilities and a parameterization of optical radiation fields, and (d) accurate radiative transfer calculations in a smaller atomic model.

The solar spectra show unambiguous evidence that electron collisions are responsible for most of the Fe II emission observed above the white-light limb. For cool giants the  $z^6D^\circ, z^6F^\circ$  terms, leading to UV multiplets 1, 32 and 2, 33, 60, are also excited primarily by electron collisions. However, the  $z^6P^\circ, z^4D^\circ, z^4F^\circ$  and  $z^4P^\circ$  terms, leading to UV multiplets 3-6, 34-36 and 61-64, cannot be excited solely by electron collisions or by previously identified line fluorescence processes. These terms are excited by electron collisional excitation of metastable quartet terms below  $\sim 4\text{eV}$ , followed by photo-excitation in lines at optical wavelengths by photospheric radiation.

We construct a "cool star" diagnostic diagram similar to the figure of Viotti (1976), showing the regimes in which electron collisions and continuum photo-excitation are important in the chromospheres of cool stars. Finally we discuss some implications of our findings.